

Translation in English

DRAFTING OF THE INVENTION

1. Title of the Invention

Pseudo Double-Layer Perpendicular Magnetic Recording Disk with Microsized Magnetic Domains

2. Brief Description of the Drawings

FIG. 1 is a sectional view showing the structure of a single-layer perpendicular magnetic recording (PMR) disk.

FIG. 2 is a sectional view showing the structure of a pseudo double-layer PMR disk with an intermediate soft magnetic layer.

FIG. 3 is a graph showing signal and noise level variations with respect to recording densities in kFRPI (kilo flux revolutions per inch) for the single-layer PMR disk of FIG. 1 (Single) and the pseudo double-layer PMR disk of FIG. 2 (Psueod).

FIG. 4 is a graph showing variations in perpendicular coercivity with respect to variations in thickness of a CoCr alloy magnetic recording layer.

(H_c : perpendicular coercivity, H_o : maximum perpendicular coercivity)

FIG. 5 is a graph showing variations in domain diameter and proportional noise level constant α with respect to variations in thickness of a PMR layer;

FIG. 6 is a graph showing variations in perpendicular coercivity ratio H_c / H_o and the perpendicular remanent magnetization ratio M_r / M_o with respect to variations in thickness of a PMR layer.

H_c : perpendicular coercivity, H_o : maximum perpendicular coercivity

M_r : perpendicular remanent magnetization, M_o : maximum perpendicular remanent magnetization

FIG. 7 is a graph showing variations in signal and noise levels with respect to recording densities in kFRPI for single-layer PMR disks having CoCr alloy magnetic recording layers which are different in thickness.

FIG. 8 is a graph showing variations in signal-to-noise ratio (SNR) with respect to recording densities in kFRPI for the single-layer PMR disks having CoCr alloy magnetic recording layers which are different in thickness.

FIG. 9 is a graph showing variations in signal and noise levels with respect to recording densities in kFRPI for pseudo double-layer PMR disks

having CoCr alloy magnetic recording layers which are different in thickness.

FIG. 10 is a graph showing variations in SNR with respect to recording densities in kFRPI for the pseudo double-layer PMR disks having CoCr alloy magnetic recording layers which are different in thickness.

FIG. 11 comparatively shows variations in SNR with respect to recording densities in kFRPI for the single-layer PMR disks having CoCr alloy magnetic recording layers (S 20 nm) and for pseudo double-layer PMR disks having CoCr alloy magnetic recording layers (P 20 nm).

3. Detailed Description of the Invention

1) Summary of the Invention

In longitudinal magnetic recording (LMR) applied to hard disk drives (HDDs), a major external data storage device of computers, the size of a data record domain in a magnetic disk has decreased with microstructure as the need for high-density data recording increases. However, this decrease in size makes the data record domains susceptible to removal by thermal energy generated by operation of the HDD which is more dominant than magnetostatic energy from the data record domain. This is referred to as the super paramagnetic effect. To overcome the super paramagnetic effect, the LMR technique has been replaced by a perpendicular magnetic recording (PMR) technique for HDD applications. The PMR technique uses a higher electrostatic energy and lower demagnetization energy compared to the LMR technique, so it is advantageous in high-density data recording.

The high-density PMR technique also has enabled detection of a micro data domain in combination with advances in the manufacture of highly sensitive read heads. However, in order to obtain a stable signal-to-noise ratio (SNR) of the data record domain, an increase of a signal level and a decrease of a noise level are required. To this, the present inventor formed micro-sized magnetic domains based on the correlation of the magnetostatic energy and magnetic field energy of a PMR layer and applied the PMR layer with the micro-sized magnetic domains to a pseudo double-layer PMR disk with a closed magnetic field structure. As a result, a low noise level and a high SNR were obtained.

2) Problems of the Prior Art

In the perpendicular magnetic recording (PMR) technique suitable for high-density magnetic recording, perpendicular magnetic anisotropy energy is exerted to orient the direction of magnetized domains perpendicular to the plane of a magnetic disk. Thus, head fields from a magnetic head should be induced to be perpendicular to the magnetic disk plane and thus parallel to the magnetized domains. To achieve this, a single-pole-type (SPT) perpendicular magnetic head is required. However, the SPT perpendicular magnetic head also generates a demagnetization field stronger than the perpendicular field of the magnetic head, so the perpendicular magnetic field induced by the SPT head is insufficient for recording, thus limiting use of the PMR technique in HDD applications.

The recent advances in magnetic recording technologies have enabled PMR with a ring-type magnetic head that has been used widely in LMP due to its ability to apply enhanced perpendicular magnetic fields for recording. Based on the PMR performed using the ring-type magnetic head, a single-layer PMR disk with a perpendicular magnetic recording/playback layer as shown in FIG. 1 has been developed. The single-layer PMR disk includes an underlayer for promoting the perpendicular orientation of a perpendicular magnetic recording/playback layer formed over a glass or aluminum alloy substrate, a PMR layer having the perpendicular magnetic anisotropy energy to keep the perpendicular orientation of the data record domain, a protective layer for protecting the PMR layer from external impacts, and a lubricant layer. The PMR layer has the perpendicular magnetic anisotropy energy with a magnetic easy axis oriented perpendicular to the plane of the PMR layer due to the underlayer. Therefore, perpendicular data recording can be achieved by perpendicular magnetic field components from a ring-type head. However, in the conventional single-layer PMR disk shown in FIG. 1, the PMR layer having the perpendicular magnetic anisotropy energy has also a large demagnetization factor and thus strong demagnetization energy is induced in a direction opposite to the magnetic moment of the PMR layer, as expressed by formula (1) below:

$$Ku_{eff} = Ku - 2\pi NdMs^2 \quad \dots(1)$$

where Ku_{eff} is the effective perpendicular magnetic anisotropy energy, Ku is the perpendicular magnetic anisotropy energy, Nd is the demagnetization factor, M_s is the saturation magnetization, and $2\pi NdM_s^2$ is the demagnetization energy.

Thus, the effective perpendicular magnetic anisotropy energy of the PMR layer is abruptly decreased with unsatisfactory high-density recording properties, thereby limiting HDD applications of the PMR technique.

To overcome the effective perpendicular magnetic anisotropy energy reduction occurring in such a single-layer PMR disk, a pseudo double-layer PMR disk capable of reducing the demagnetization energy of its PMR layer has been developed. In the pseudo double-layer PMR disk, as shown in FIG. 2, an intermediate soft magnetic layer 3-1 is deposited between a perpendicular orientation promoting underlayer 2 and a PMR layer 3 to allow formation of a closed magnetic circuit through the PMR layer by perpendicular magnetic field components from a ring-type head. The closed magnetic circuit formed by the intermediate soft magnetic layer reduces the demagnetization factor of the PMR layer and its demagnetization energy, and thereby limits reduction in the effective perpendicular magnetic anisotropy energy.

FIG. 3 is a graph showing signal and noise level variations with respect to recording densities in kFRPI (kilo flux revolutions per inch) for the signal-layer PMR disk shown in FIG. 1 (single disk) and the pseudo double-layer PMR disk with the intermediate soft magnetic layer shown in FIG. 2 (pseudo disk). The pseudo double-layer PMR disk shows a higher signal output than the single-layer PMR disk due to retention of the effective perpendicular magnetic anisotropy energy by the intermediate soft magnetic layer that reduces the demagnetization energy by forming a closed magnetic circuit through the PMR layer. However, the intermediate soft magnetic layer is also likely to cause a random orientation of neighboring magnetic fields and results in additional noise (jitter), so the pseudo double-layer PMR disk has a higher noise level than the single-layer PMR disk. Due to increases in both the signal and noise levels, the pseudo double-layer PMR disk has a signal-to-noise ratio (SNR) which is too small for high-density recording. Therefore, there is a need to reduce a noise output level originating from the PMR layer of the pseudo double-layer PMR disk to obtain a SNR large enough for high-density recording.

3) Construction of the Invention

In increasing the signal-to-noise ratio (SNR) of a pseudo double-layer perpendicular magnetic recording (PMR) disk, a noise level should be reduced while keeping a signal level of a PMR layer constant. Noise levels are proportional to a noise level constant α which is proportional to the average diameter of reversed magnetic domains formed in the PMR layer, as expressed by formula (2) below:

$$\alpha = \frac{4\pi Mr}{Hc} \quad \dots(2)$$

where Mr is the perpendicular remanent magnetization and Hc is the perpendicular coercivity. Therefore, there is a need to reduce the diameter of magnetic domains in the PMR layer to reduce the noise level.

The domain diameter in the PMR layer is dependent on the balance between the magnetostatic energy and domain wall energy. In particular, to lower the magnetostatic energy, there is a need to divide domains in the PMR layer into a number of micro-sized magnetic domains to form closed magnetic loops. However, the domain wall energy is increased due to the increased number of micro-sized magnetic domains, thereby increasing the total energy level of the PMR layer. Consequently, to minimize the total energy of the PMR layer, i.e., the sum of the electrostatic energy and domain wall energy, expressed as formula (3) above, the domain diameter D is determined based on formula (4) below:

$$E_{tot} = E_{ms} + E_{wall} = 1.7 Ms^2 D + \gamma L / D \quad \dots(3)$$

where E_{tot} is the total energy of the PMR layer, E_{ms} is the electrostatic energy of the PMR layer equivalent to $1.7Ms^2D$, E_{wall} is the domain wall energy of the PMR layer equivalent to $\gamma L / D$, Ms is the saturation magnetization, D is the domain diameter, γ is the domain wall energy, and L is the thickness of the PMR layer.

$$D = \sqrt{\frac{\gamma L}{1.7 Ms^2}} \quad \dots(4)$$

As is apparent from formula (4) above, the thickness L of the PMR layer in a pseudo double-layer PMR disk can be decreased to reduce the domain diameter D in the PMR layer and thereby to lower noise levels.

4) Operational Principle of the Invention

In manufacturing a conventional single-layer perpendicular magnetic recording (PMR) disk, to reduce a noise level of its PMR layer, the thickness of the PMR layer is determined to be a point at which the perpendicular coercivity H_c has a maximum value, thereby resulting in a minimal value of the noise level constant of proportionality α ($\alpha = 4\pi Mr/H_c$). As an example, for a CoCr alloy magnetic recording layer of a conventional PMR disk, the perpendicular coercivity H_c is abruptly decreased at a recording layer thickness no greater than 50 nm, as shown in FIG. 4. Thus, the CoCr alloy magnetic recording layer is formed to be thicker than 50 nm in the conventional PMR disk for noise level control.

However, a high-coercivity magnetic recording layer as thick as 50 nm or greater as shown in FIG. 4 is not enough to reduce the noise level constant of proportionality α for a pseudo double-layer PMR disk (see FIG. 3). For this reason, in case of using the above magnetic layer as a PMR layer for a pseudo double-layer PMR disk, there occur additional noises (jitter) in the pseudo double-layer PMR disk due to the use of the intermediate soft magnetic layer, thereby resulting in a high noise level. Accordingly, the SNR is poor.

In a pseudo double-layer PMR disk according to the present invention, the thickness of a CoCr alloy magnetic recording layer is reduced to a thickness at which the perpendicular coercivity decreases, and micro-sized magnetic domains are formed in the CoCr alloy magnetic recording layer, thereby lowering noise levels with improved SNR.

To this, pseudo double-layer PMR disks are manufactured as follows. Ti underlayers that induce the perpendicular orientation of PMR layers are formed to a thickness of 50-100 nm on glass or aluminium alloy substrates by vacuum deposition, soft magnetic layers made of NiFe alloy are formed on the underlayers to a thickness of 3-10 nm, and then CoCr alloy magnetic recording layers as the PMR layers are formed thereon to different thicknesses of 15-100 nm. Next, protective layers and lubricant layers are sequentially formed on the CoCr alloy magnetic recording layers. On the other hand, as a comparative

example, single-layer PMR disks are manufactured as follows. Ti underlayers that induce the perpendicular orientation of PMR layers are formed to a thickness of 50-100 nm on glass or aluminium alloy substrates by vacuum deposition, and then CoCr alloy magnetic recording layers as the PMR layers are formed thereon to different thicknesses of 15-100 nm. Next, protective layers and lubricant layers are sequentially formed on the CoCr alloy magnetic recording layers.

FIG. 5 shows the variations in domain diameter with respect to variations in thickness of CoCr alloy magnetic recording layers in the pseudo double-layer PMR disks thus manufactured. As shown in FIG. 5, decreases in domain diameter were observed at a magnetic recording layer thickness smaller than the thickness at which the perpendicular coercivity H_c starts to decrease. Apparently, micro-sized magnetic domains were formed at a reduced thickness of the magnetic recording layers. Also, the formation of micro-sized magnetic domains in the magnetic recording layer induced a sharp reduction of the noise level constant of proportionality α , as shown in FIG. 5.

5) Effect of the Invention

FIG. 6 is a graph showing the variations in perpendicular coercivity ratio (H_c / H_0) and perpendicular remanent magnetization ratio (M_r / M_0) with respect to variations in thickness of the CoCr alloy magnetic recording layers of the pseudo double-layer PMR disks of FIG. 5. As shown in FIG. 6, the perpendicular remanent magnetization ratio (M_r / M_0) shows a sharp reduction with respect to variations in thickness of the CoCr alloy magnetic recording layers, when compared to the perpendicular coercivity ratio (H_c / H_0). This sharp reduction in the perpendicular remanent magnetization ratio (M_r / M_0) with reduced thickness of the magnetic recording layers, which is due to the formation of micro-sized magnetic domains, reduces the noise level constant of proportionality α .

Uniform CoCr alloy magnetic recording layers with a thickness of less than 20 nm cannot be manufactured with a modern PMR technique. For this reason, a reliable noise level constant of proportionality cannot be obtained. However, in the future, an advanced vapor deposition technique will enable to manufacture of ultra thin magnetic alloy layers with a thickness of less than 20 nm. Therefore, the formation of uniform, micro-sized magnetic domains would enable to manufacture of pseudo double-layer PMR layers with a low noise

level constant of proportionality and pseudo double-layer PMR disks with the PMR layers.

4. Claims

Independent claim:

1) A pseudo double-layer perpendicular magnetic recording (PMR) disk having a CoCr alloy magnetic recording layer with perpendicular magnetic anisotropy energy, in which a noise level constant of proportionality decreases and a signal-to-noise ratio (SNR) is good as a result of reduction of the domain diameter of the magnetic recording layer with reduced thickness of the magnetic recording layer.

Dependent claims:

1) In the pseudo double-layer PMR disk, the domain diameter decreases in the range of thickness of the magnetic recording layer at which perpendicular coercivity decreases.

2) In the pseudo double-layer PMR disk, in the range of thickness of the magnetic recording layer at which perpendicular coercivity decreases, the rate of variation of the ratio of perpendicular remanent magnetization M_r to maximum perpendicular remanent magnetization M_o is greater than that of the ratio of perpendicular coercivity H_c to maximum perpendicular coercivity H_o .

3) In the pseudo double-layer PMR disk, in the range of thickness of the magnetic recording layer at which perpendicular coercivity decreases, a noise level constant of proportionality α decreases.

4) In the pseudo double-layer PMR disk, the magnetic recording layer is made of a CoCr alloy and further comprises at least one material selected from the group consisting of B, Pt, Ta, V, Nb, Zr, Y, and Mo.

5) In the pseudo double-layer PMR disk, the magnetic recording layer has a thickness of 20-50 nm, preferably less than 20 nm.

6) In the pseudo double-layer PMR disk, an intermediate soft magnetic layer is made of a NiFe alloy and further comprises at least one material selected from the group consisting of Nb, V, Ta, Zr, Hf, Ti, B, Si, and P.

7) In the pseudo double-layer PMR disk, the the intermediate soft magnetic layer has a thickness of 3-10 nm.

8) The pseudo double-layer PMR disk is compatible with a ring-type magnetic record head for recording and a magneto-resistive (MR) read head for reproducing.

5. Example

FIG. 7 is a graph showing variations in signal and noise levels in a single-layer perpendicular magnetic recording (PMR) disk having a conventional CoCr alloy magnetic recording layer (50 nm) and single-layer PMR disks having CoCr alloy magnetic recording layers of the present invention (35 nm and 20 nm). As shown in FIG. 7, the single-layer PMR disks having 35- and 20-nm thick CoCr alloy magnetic recording layers of the present invention exhibited a high signal level and a low noise level, when compared to the single-layer PMR disk having a conventional CoCr alloy magnetic recording layer. Variations in signal-to-noise ratio (SNR) with respect to recording densities in kFRPI for these single-layer PMR disks are shown in FIG. 8.

FIG. 9 is a graph showing variations in signal and noise levels in a pseudo double-layer PMR disk having a conventional CoCr alloy magnetic recording layer (50 nm) and pseudo double-layer PMR disks having CoCr alloy magnetic recording layers of the present invention (35 nm and 20 nm). The pseudo double-layer PMR disks exhibited a high signal level, when compared to the single-layer PMR disks of FIG. 7. With respect to a noise level, the pseudo double-layer PMR disks exhibited a high noise level due to incorporation of the intermediate soft magnetic layer, when compared to the single-layer PMR disks of FIG. 7. However, the pseudo double-layer PMR disks exhibited a remarkably reduced noise level with a reduced thickness of the alloy magnetic recording layer. Variations in SNR with respect to recording densities in kFRPI for these pseudo double-layer PMR disks are shown in FIG. 10.

FIG. 11 comparatively shows the variations in SNR with respect to recording densities in kFRPI for the conventional single-layer and pseudo

double layer PMR disks having a 50-nm-thick CoCr alloy magnetic recording layer and for the single-layer and pseudo layer PMR disks having a 20-nm-thick CoCr alloy magnetic recording layer according to the present invention. A great improvement in SNR was observed for the pseudo double layer PMR disk according to the present invention having a magnetic recording layer as thin as 20 nm with micro-sized magnetic domains.

6. Drawings

FIG. 1

Lubricant layer (5)

Protective layer (4)

Perpendicular magnetic recording layer (3)

Perpendicular orientation promoting underlayer (2)

Substrate (1)

FIG. 2

Lubricant layer (5)

Protective layer (4)

Perpendicular magnetic recording layer (3)

Intermediate soft magnetic layer (3-1)

Perpendicular orientation promoting underlayer (2)

Substrate (1)